

## FIVE-SEGMENT SOLID ROCKET MOTOR DEVELOPMENT STATUS

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### ABSTRACT

In support of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) is developing a new, more powerful solid rocket motor for space launch applications. To minimize technical risks and development costs, NASA chose to use the Space Shuttle's solid rocket boosters as a starting point in the design and development. The new, five segment motor provides a greater total impulse with improved, more environmentally friendly materials. To meet the mass and trajectory requirements, the motor incorporates substantial design and system upgrades, including new propellant grain geometry with an additional segment, new internal insulation system, and a state-of-the-art avionics system. Significant progress has been made in the design, development and testing of the propulsion, and avionics systems. To date, three development motors (one each in 2009, 2010, and 2011) have been successfully static tested by NASA and ATK's Launch Systems Group in Promontory, UT. These development motor tests have validated much of the engineering with substantial data collected, analyzed, and utilized to improve the design. This paper provides an overview of the development progress on the first stage propulsion system.

### INTRODUCTION

The Space Launch System (SLS), NASA's current initiative, leverages the success of the Space Shuttle Program (SSP) and Ares Project. The Ares Project utilized the Shuttle's strap-on solid rocket boosters as a starting point for the in-line, Ares I first stage motor design. The Ares I first stage booster completed two full-scale static motor tests and several other system level tests including avionics, pyrotechnics, and parachute drop tests. However, NASA cancelled the Ares Project in 2010 and transitioned into SLS.

The goal of SLS is to develop a safe, affordable, and sustainable heavy-lift capability for NASA. The SLS vehicle is composed of two strap-on boosters, a core stage, and an upper stage config-

ured for a capsule or science payloads, providing a flexible/modular design for multiple launch needs. The SLS vehicle is an evolvable design that begins with an initial payload capability of 70 metric tons (t). This initial vehicle design, designated Block 1, will fly its maiden, unmanned flight in 2017 with a manned flight in 2021. The follow-on, evolvable designs, designated Block 1A and 2, will deliver payload capabilities of 105 t and 130 t, respectively, with flights beginning after 2021.



Figure 1. Artist Rendition of SLS Block 1 launch.

The Block 1 design provides the primary transportation for the Orion capsule and exploration missions and capitalizes on existing assets in storage. The core stage is powered by existing SSP assets of RS25s (Space Shuttle Main Engines). The five-segment solid rocket motor (RSRMV) also utilizes existing assets from the SSP to provide the primary liftoff propulsion. The Block 1A vehicle design replaces the solid strap-on boosters

with new advanced boosters. The advanced booster will provide improved performance by either liquid or solid propulsion. The design, development, test, and evaluation (DDT&E) of these advanced boosters will be awarded by a competitive procurement. The evolution from Block 1A to Block 2 adds an upper stage powered by J-2X engines. The Block 1A and 2 launch vehicles will continue to provide service for Orion and exploration missions while offering a large volume for science missions and payloads.

### BOOSTER DESIGN OVERVIEW

Careful consideration was given to all historical booster design and concept of operations assumptions in order to achieve the most cost efficient booster for the initial two flights. Consequently, the Block 1 booster design is expendable and will not be recovered. Similar to Shuttle and Ares, the Block 1 SLS booster design incorporates three assemblies: the forward assembly, solid rocket motor, and the aft assembly. The forward assembly design changed considerably with the removal of parachutes. Designing to a strap-on vehicle configuration, the boosters will provide the primary propulsion for liftoff and structural support, serving as the backbone of the system, transmitting the weight load through the structure to the mobile launch platform for all conditions prior to vehicle launch.

The Block 1 DDT&E effort is underway utilizing existing assets and the Ares I First Stage contract. The Block 1A and 2 designs will be determined later in the program through a competitive procurement process. Consequently, this paper will focus on the Block 1 booster DDT&E effort.

### DEVELOPMENT MOTOR TESTING

#### *Static Test Overview*

Full-scale static testing provides the opportunity to evaluate a number of design, material, process and supplier features for the new five-segment solid rocket motor. Three, full-scale static motor tests have been conducted to date at ATK in Promontory, Utah.

Development Motor #1 (DM-1) was successfully conducted September 10, 2009 as the first full-scale, full-duration test of the newly designed five-segment motor. The motor was tested in ambient condition with Propellant Mean Bulk Temperature

(PMBT) of 80 degrees Fahrenheit (F) at time of test. The post-test inspections and data gained through 650 instrumentation channels verified the 46 test objectives and validated the design of the five-segment solid rocket motor.



**Figure 2. DM-1 Static Test.**

The second static test, Development Motor #2 (DM-2), was completed on September 7, 2010 at ATK. Although similar in design to DM-1, different features were integrated into DM-2, most notably a cold temperature test where the nominal PMBT was 40 degrees F to understand motor performance at low temperature extremes. DM-2 also characterized the integrity of a new insulation material in the aft dome as well as a different tape wrap, or ply, angle within the nozzle. Additionally, DM-2 included intentional “flaws” to test the secondary, or redundant, capture and sealing features in the field joints. The motor was instrumented with 764 instrumentation channels obtaining data to verify 53 design objectives.

The third, and final, development motor was successfully tested on September 8, 2011. The static test covered 37 objectives with 979 instruments collecting the necessary data. The DM-3 was a hot conditioned motor test with a PMBT of 93 degrees

F to verify the motor's design against higher pressure, loads, and temperature. Although similar to DM-2, the design of DM-3 reduced the insulation weight by approximately 1300 pounds, as compared to DM-2, and incorporated a nozzle with different materials and more optimal contours.



Figure 3. DM-3 Static Test.

With the development motor testing complete, the test results and data analysis supported the engineering development while providing an understanding of the motor ballistics, internal insulation performance, and nozzle performance. The team is currently evaluating the motor design through Qualification Readiness Reviews (QRRs). These QRRs finalize the motor design prior to entering the qualification test phase. Upon completion of the QRRs, Qualification Motor #1 (QM-1) will be manufactured and static tested in spring 2013. A second qualification motor test is scheduled for 2014, completing the static testing and qualifying the motor design for flight.

### Motor Performance

The SLS boosters provide most of the vehicle's propulsion during the first two minutes of flight. The Block 1 booster motor consists of five segments: a forward segment, three center segments, and an aft segment. The SLS booster propellant is based upon the Shuttle's Reusable Solid Rocket Motor (RSRM) Polybutadiene acrylonitrile (PBAN) propellant formulation with only minor modifications. The new grain design provides a unique thrust-time profile translating into approximately twenty-five percent increase in total impulse over the Shuttle RSRMs. The three static tests provided significant performance data that allowed the ballistics models to be updated to more accurately predict the true motor's performance during a flight.

Being the first full-scale test, data acquisition from DM-1 was imperative to evaluate and update, if needed, the analytical models that predict the mo-

tor's performance. All DM-1 performance parameters were within contract end item (CEI) specification requirements. However, the reconstructed performance was below prediction with total impulse values approximately 0.5% below prediction. During the investigation, it was found that the motor performance models over predicted efficiency. Consequently, the analytical prediction models were updated to reflect performance predictions based upon DM-1 test results.

The final two static test motors, DM-2 and DM-3, performed similar to DM-1 with total impulse measurements 0.3% greater and 0.1% less, respectively, than the updated analytical models. All performance parameters of DM-2 and DM-3 were within CEI specification requirements.

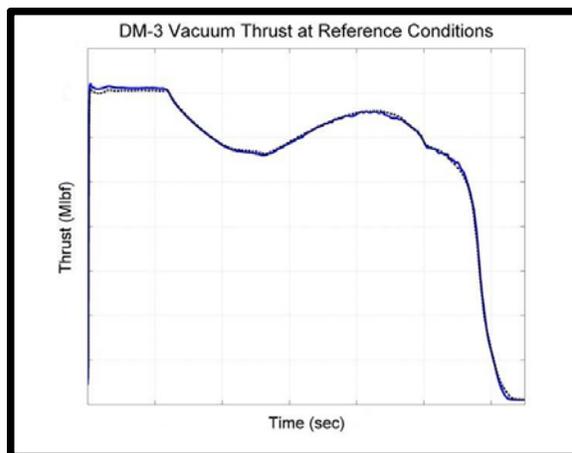


Figure 4. DM-3 Vacuum Thrust Trace.

### Insulation Performance

The Shuttle's Reusable Solid Rocket Motor (RSRM) baseline design used asbestos and silica-filled nitrile butadiene rubber (ASNBR) as an insulator. The asbestos fibers are also known as chrysotile fibers. Due to the inherent health issues involved in the manufacture, layup, and removal of ASNBR insulator on motor cases, Kirkhill Rubber Company developed new formulations of non-chrysotile insulators as candidates to replace the Shuttle ASNBR. Five rubber formulations were later tested on Shuttle Flight Support Motors – 13 and 14. An insulator called polybenzimidazole nitrile butadiene rubber (PBI-NBR), which is composed of a polymer, PBI fiber, and Nanoclay filler, was the only insulator exhibiting acceptable performance and was chosen to replace ASNBR.

In addition to PBI-NBR's ability to provide adequate insulation without the use of chrysotile

fibers, other properties of PBI-NBR also make it an attractive insulator. Improvements in material properties included lower density, significantly lower thermal conductivity, and a higher specific heat. Consequently, the overall thermal diffusivity of PBI-NBR was considerably lower than ASNBR and enabled the reduction in total insulation weight for the baseline design of the Ares first stage, and now the SLS booster motor. Typical insulation weight on a four-segment RSRM was approximately 20,500 pounds whereas the five-segment SLS booster motor is baselined at approximately 18,600 pounds. The insulation reduction was primarily accomplished in the insulated segments with the Center aft and aft segments showing the most reduction.



**Figure 5. DM-2 Aft Dome Post-test Inspection.**

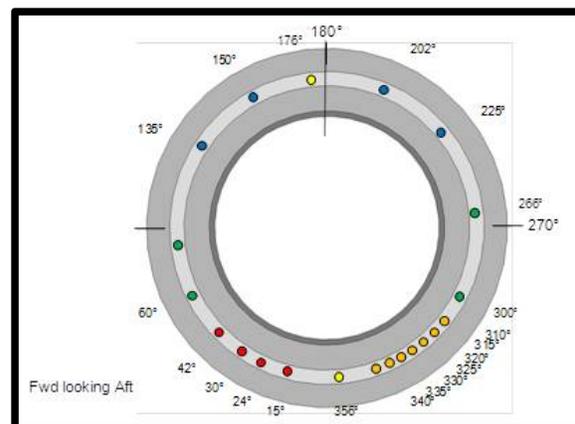
Erosion data for the PBI-NBR insulator has been obtained from the DM-1, DM-2, and DM-3 static tests. It appears the new insulator performs best primarily in high flow regions such as factory joints, tang buildup, and aft segment. Regions of high exposure and low flow such as the forward segment typically showed slightly higher material loss than originally predicted. In addition, regions of low exposure such as the center segments also show slightly higher material loss than predicted. With the replacement of ASNBR by PBI-NBR, the SLS booster benefits from a less dense and higher performing material that is much less harmful to those involved in the manufacture, application, and

removal of the insulator.

### ***Nozzle Performance***

During post-test inspection of the DM-1 and DM-2 nozzle inlets, wash erosion of the Nozzle forward nose ring (FNR) was up to 0.9 inch deeper than surrounding erosion conditions. Although the erosion was within specification on both motors, the DM-2 FNR erosion was more severe than DM-1. Moreover, the primary location of excessive erosion was heavily biased to the bottom side of the motor (relative to the horizontal motor configuration for static tests). Consequently, a team was formed with hopes of providing an explanation or plan of action to address the phenomena.

Although the team knew abnormal erosion was occurring in the FNR, no test data was available to determine if the erosion occurred within a specific time during the two-minute static test or if it was a linear effect throughout the entire test duration. The team initiated plans to instrument the upcoming DM-3 nozzle FNR with 42 ultrasonic transducer (UT) gauges at 21 locations, with 15 gauges located on the bottom side (See Figure 6). With the use of UT gauges, a time-lapsed char line regression may be measured and analytical models validated.



**Figure 6. DM-2 Aft Dome Post-test Inspection.**

The DM-3 UT data indicated the 15 degree and 24 degree gauges measured the abnormal erosion. The gauges also indicated that this erosion phenomenon occurred during the first twenty-three seconds of burn. Nominal erosion was detected from 60 to 225 degrees.

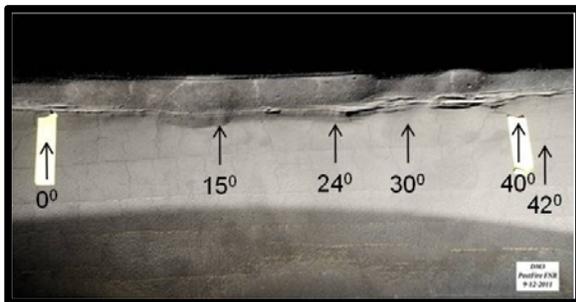


Figure 7. DM-3 FNR Post-test.

In addition to full-scale UT data, small subscale motor testing and CFD analysis were conducted to identify the root cause of the abnormal FNR erosion. It was determined that thermally driven ply slough and structural interlaminar failure contribute to high material loss at forward end of FNR at ~16 seconds into motor operation. Motor sag due to the horizontal motor orientation also worsened the thermal environment.

Consequently, the team determined that nozzle design changes as well as changes in the static test support system were needed. Proposed nozzle design changes include material changes with a slightly different ply angle. Also, additional mid-span support system will be utilized on QM-1 and QM-2.

### Thrust Oscillation Performance

Solid rocket motors create acceleration loads due to internal pressure oscillations. Early estimates of potential acceleration loads imposed upon the Orion capsule led to a desire to eliminate or mitigate the resultant motor thrust oscillations. A team was formed in January 2009 with the charter to investigate, develop and demonstrate design options at the first stage booster level to eliminate or mitigate the generation of thrust oscillations. Follow on work centered on data analysis, understanding fundamental phenomena, numerical modeling, advancing instrumentation and developing advanced analytical techniques. The primary focus of this follow-on effort was to reduce uncertainty in the predicted thrust oscillations for the RSRMV motor.

The developed analytical models predicted the DM-1 static test maximum 1-L amplitudes to be from 0.5 to 1.9 psi zero-to-peak. However, the maximum value measured on DM-1 was 0.46 psi, indicating that the prediction models were conservative. Also, the 2-L and 3-L amplitudes were

lower than RSRM and other historical motor amplitudes. Similar oscillation measurements were found on DM-2 and DM-3 static tests as well. For example, the maximum 1-L amplitude measured on both development motors were 0.51 and 0.49, respectively. Consequently, significant improvements were made to the analytical models, enhancing the prediction accuracy for the motor pressure oscillation behavior. Based upon the test data and improved analytical models, it was evident that fewer, or no, mitigation mechanisms would be needed to dampen the pressure oscillations.

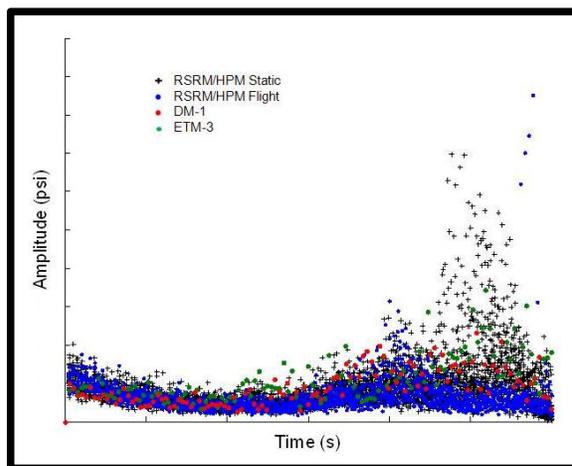


Figure 8. DM-1 1-L Maximum Pressure Oscillation Amplitude Comparison.

### AVIONICS TESTING

Significant development, fabrication and testing has been accomplished to date on the first stage avionics boxes and components. The booster avionics boxes include the Ignition Separation Controller (ISC), Hydraulic Power Unit Controller (HPUC), and the Booster Control Power Distribution Unit (BCPDU). Together, these boxes control the stage, take measurements, and communicate with the rest of the vehicle. The objective of the avionics testing was to exercise the flight design functionality through all flight phases and serves as a test bed for certification testing.

The initial phases of testing manufactured the first generation (Revision 0) components and Engineering Development Units (EDUs) in 2010. Hard environment testing, such as thermal test, was conducted at Cincinnati Electronics (CE) on each component of the EDUs to evaluate the performance during flight-like conditions.

After the successful box-level testing, the first generation EDUs (ISC, HPUC, and BCPDU) were integrated into a test chassis at ATK in a single string configuration to simulate flight-like commands being sent through the BCPDU to the ISC and HPUC. The single string test was successfully completed in January 2011.

Following the single string tests, upgraded Revision 1 EDUs were manufactured and integrated into a full-scale forward structure model in a flight-like, multi-string configuration. In addition to testing the avionics boxes ability to withstand the various flight-like environmental conditions, this also tested the actual spacing and cable routing between the boxes in a flight-like model. The EDUs were then subjected to environmental qualification level testing (vibration, shock, EMI, salt/fog, etc.). This qualified the avionics boxes to the environmental bounds through all phases of flight.



**Figure 9. ISC EDU Integrated into Controlled Demonstration Test at MSFC.**

An additional test integrated the Revision 1 EDUs into a controlled demonstration test at Marshall Space Flight Center. The test managed the thrust vector control actuators and tested the control commands of the avionics boxes during a simulated flight.

#### **LIFE CYCLE COST AND VALUE STREAM MAPPING**

In 2008, NASA established a team to evaluate the design-to-cost (DTC) estimate and develop ways to significantly reduce production cost for the Ares I First Stage booster. The team identified significant cost drivers with one being NASA's culture of insight and oversight. NASA and ATK have typically maintained high levels of interface

throughout the design and production process without restricting those interaction points. NASA reduced the number of official avenues for contractor direction, which also reduced the workforce burden on ATK to address NASA actions.

Beginning in 2011, NASA and ATK began utilizing a value stream mapping (VSM) process to identify ways for streamlining and optimizing processes for manufacturing and assembling SLS boosters. ATK has completed the VSM process for all major motor production areas, including metal refurbishment, insulation, propellant, nozzle, and final assembly. VSMs will also be conducted on booster separation motor (BSM) and test area processing. ATK identified nearly 750 changes that would eliminate more than 400 hardware moves. These improvements would reduce cycle times by approximately 46% and reduce projected costs by millions of dollars, with no significant increased risk to the hardware, mission, and program. The fabrication and processing of QM-1 is underway and implementing these improvements.

#### **CONCLUSION AND TECHNICAL STATUS**

Strap-on, solid rocket motors manufactured by ATK provide the primary liftoff propulsion to the SLS Block 1 launch vehicle. Block 1A and 2 designs for SLS will be competitively bid through a full and open competition. Currently, the SLS Booster team is progressing with the Block 1 booster design, utilizing the Ares first stage motor with most design changes occurring in the forward structures.

The SLS booster team has incorporated improvements within the design and processing of the booster. An asbestos-free insulator, new avionics, and improved manufacturing and processing techniques have increased safety, reliability while reducing costs. Three development motor tests are complete with qualification testing scheduled to begin in spring 2013. Additional testing to date has focused on the avionics and controls system. The design, development, and testing of the five-segment SLS Block 1 booster design is progressing rapidly and on schedule to meet the 2017 SLS flight.

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## Five-Segment Solid Rocket Motor Development Status

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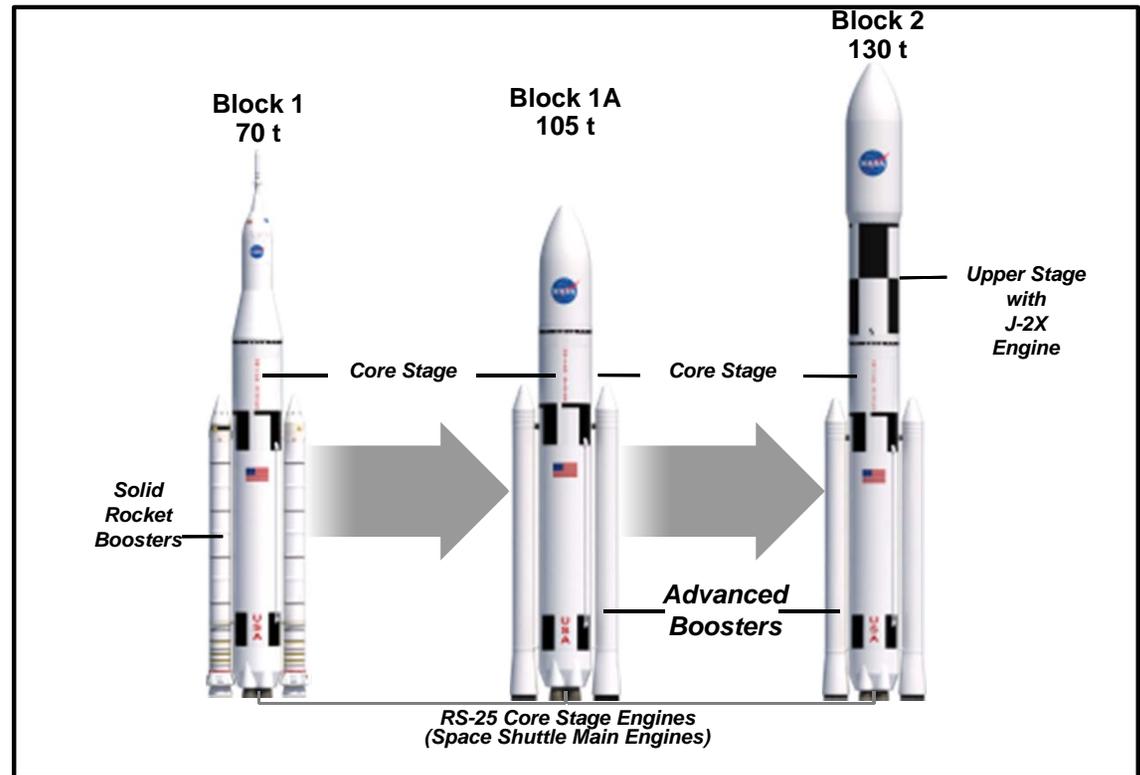
- ◆ **Introduction**
- ◆ **Booster Design Overview**
- ◆ **Development Motor Testing**
  - Static Test Overview
  - Motor Performance
  - Insulation Performance
  - Nozzle Performance
  - Thrust Oscillation Performance
- ◆ **Avionics Testing**
- ◆ **Life Cycle Cost and Value Stream Mapping**
- ◆ **Conclusions**

- ◆ **Building on the successful Space Shuttle and Ares programs, the Space Launch System (SLS) is developing a safe, affordable, and sustainable heavy-lift capability for NASA.**
- ◆ **The SLS vehicle is an evolvable design that minimizes unique configurations during vehicle development**
  - Evolutionary path to 130 t allows incremental development
  - Allows early flight certification for Orion
  - May be configured for Orion or science payloads, providing flexible/modular design and system for varying launch needs
  - Gains synergy by building the Core Stage and Upper Stage in parallel
- ◆ **SLS evolutionary design**
  - Block 1 design utilizes RS25 engine and solid rocket motor (SRM) assets to deliver 70 metric tonne (t) to orbit
  - The Block 1A vehicle design replaces the SRMs with advanced boosters to deliver 105 t payloads.
  - Up to 130 t payloads will be delivered by the Block 2 vehicle, which adds an upper stage powered by J-2X engines.



## ◆ Block 1 Booster Configuration

- Two flights (2017 and 2021)
- Utilizes existing hardware/contracts
  - ATK prime contractor
- Heritage hardware/design
  - Forward structures
  - Metal cases
  - Aft skirt
  - Thrust Vector Control
- Upgraded hardware/design
  - Expendable design
  - New avionics
  - Asbestos-free insulation
  - Five-segment solid rocket motor
    - Increased performance
    - Addition segment
    - Unique thrust-time profile



## ◆ Block 1A/2 Booster Configuration

- Used in flights beyond 2021
- DDT&E will be awarded by a competitive procurement.
- Improved performance by either liquid or solid propulsion

◆ **This paper focuses on the Block 1 booster design, development, test, and evaluation (DDT&E).**

- ◆ **Development Motor #1 (DM-1) conducted on September 10, 2009**
  - 650 instrumentation channels verified 46 total objectives
  - Ambient temperature test – Propellant Mean Bulk Temperature (PMBT): 80° Fahrenheit (F)
  - Validated the design of the RSRMV
- ◆ **DM-2 conducted on September 7, 2010**
  - 764 instrumentation channels verified 53 total objectives
  - Cold temperature test – PMBT: 40° F
  - New aft dome insulation material and intentional “flaws” tested secondary sealing features
- ◆ **DM-3 conducted on September 8, 2011**
  - 979 instrumentation channels verified 37 total objectives
  - Hot temperature test – PMBT: 93° F
  - Reduced insulation weight and a nozzle with different materials and more optimal contours



DM-3 Static Test



DM-1 Nozzle post-fire inspection

◆ **SLS Block 1 booster propellant is based upon heritage Polybutadiene acrylonitrile (PBAN) propellant formulation with minor modifications.**

- New grain design provides approximately 25% increase in total impulse
  - Unique thrust-time profile
  - Additional center segment
  - Increased number of fins in forward segment
  - Modified burn rate

◆ **Development Motor #1**

- Total impulse values approximately 0.5% below prediction
  - Motor performance models over predicted efficiency
- Models updated to reflect performance predictions based upon DM-1 test results.

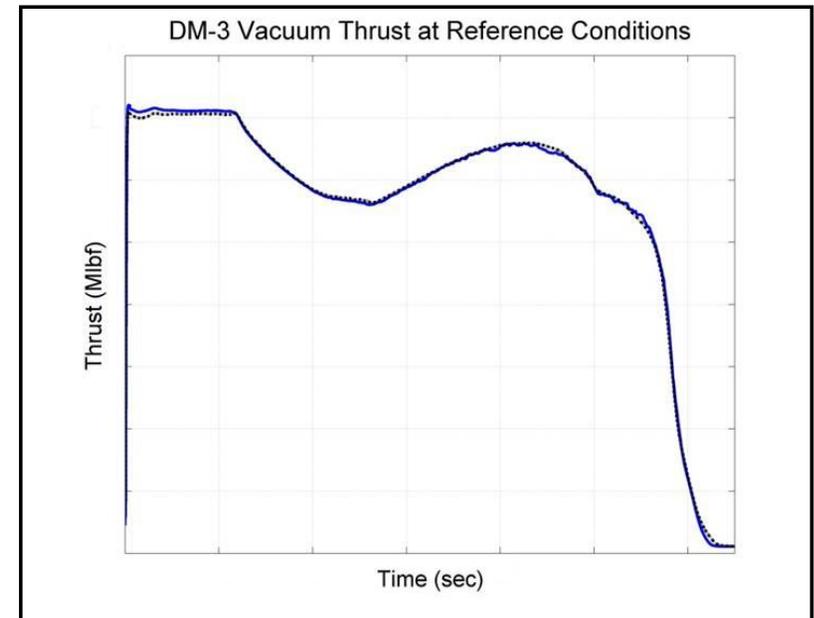
◆ **Development Motor #2**

- Total impulse approximately 0.3% greater than updated models

◆ **Development Motor #3**

- Total impulse approximately 0.1% less than updated models

◆ **Although performance parameters of DM-1, DM-2, and DM-3 were within specification, static testing provided data to update models to more accurately predict the motor's performance .**



DM-1 Static Test

- ◆ **Shuttle's Reusable Solid Rocket Motor (RSRM) baseline design used asbestos and silica-filled nitrile butadiene rubber (ASNBR) as an insulator.**
  - Inherent health issues involved in the manufacture, layup, and removal of ASNBR
- ◆ **Kirkhill Rubber Company developed a new formulation of non-asbestos insulator called polybenzimidazole nitrile butadiene rubber (PBI-NBR)**
  - Composed of a polymer, PBI fiber, and Nanoclay filler
  - Improved material properties
    - Lower density
    - Significantly lower thermal conductivity
    - Higher specific heat
  - Overall thermal diffusivity of PBI-NBR considerably lower than ASNBR and allowed total insulation weight reduction
    - Typical insulation weight on a four-segment RSRM was approximately 20,500 pounds whereas the five-segment SLS booster motor is baselined at approximately 18,600 pounds.
- ◆ **Static testing provided erosion data to accurately characterize its performance**
  - PBI-NBR insulator performed best in high flow regions such as factory joints, tang buildup, and aft segment.
- ◆ **SLS booster benefits from a less dense and higher performing insulator that is much less harmful to those involved in the manufacture, application, and removal of the insulator.**



Layup process of PBI-NBR insulator



Post-test inspection of DM-1 insulator

◆ **Post-test inspection of the DM-1 and DM-2 nozzle inlets indicated wash erosion of the Nozzle forward nose ring (FNR) was up to 0.9 inch deeper than surrounding erosion conditions**

- Primary location heavily biased to bottom side of motor (relative to horizontal motor configuration for static tests)
- No test data available to determine timing of event
- Instrument DM-3 nozzle FNR to gain time-lapsed char line regression data and validate analytical models
  - 42 ultrasonic transducers (UT) at 21 locations (15 gauges located on the bottom side)

◆ **DM-3 UT data analysis**

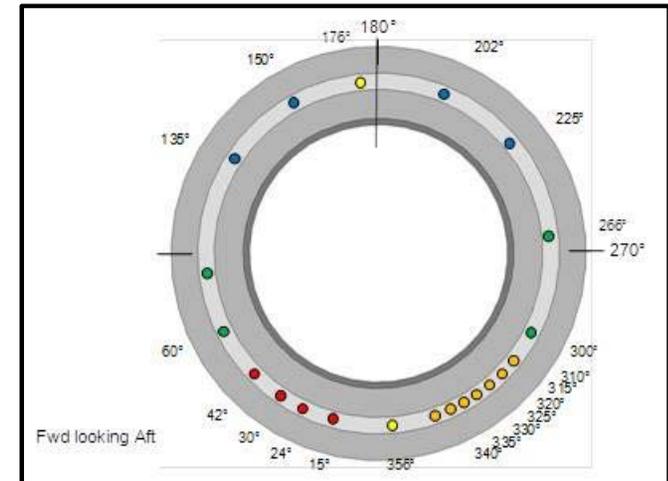
- The 15<sup>0</sup> and 24<sup>0</sup> gauges measured the abnormal erosion
- Erosion phenomenon occurred during the first 23 seconds of burn.
- Nominal erosion was detected from 60 to 225 degrees.

◆ **Small subscale motor testing and CFD analysis also conducted**

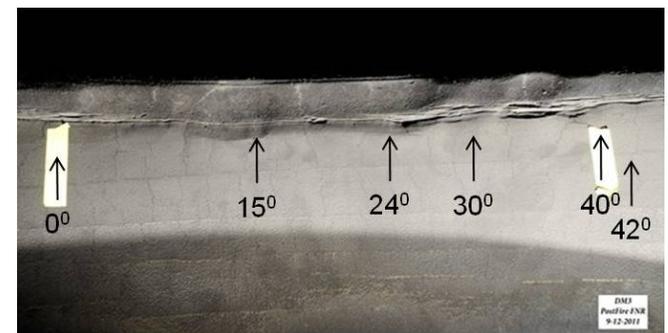
- Thermally driven ply slough and structural interlaminar failure contribute to high material loss of FNR at ~16 seconds into motor operation.
- Motor sag (horizontal motor orientation) worsened the thermal environment.

◆ **Proposed changes**

- Nozzle material changes with a slightly different ply angle
- Additional mid-span support system(s) will be utilized on QM-1 and QM-2 to reduce motor sag



DM-3 UT locations



DM-3 FNR post-test

◆ **Internal pressure oscillations within solid rocket motors create acceleration loads**

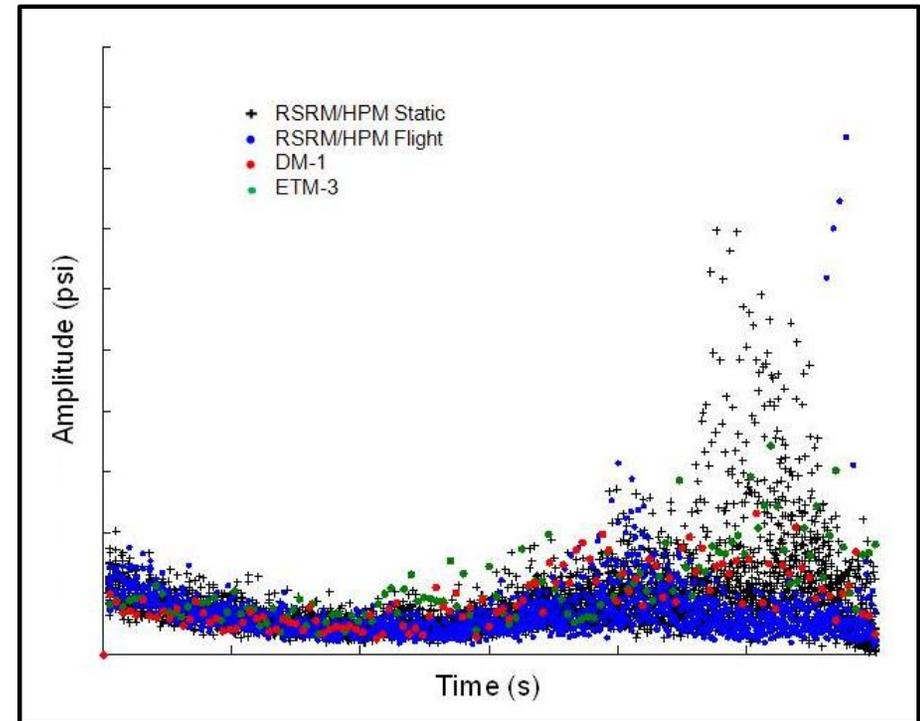
- Desire to eliminate or mitigate Orion acceleration loads (based on early estimates) from SRM
- Team formed to investigate, develop and demonstrate design options at the first stage booster level
- Later work centered on data analysis, understanding fundamental phenomena, numerical modeling, advancing instrumentation and developing advanced analytical techniques.
  - Primary focus to reduce uncertainty in the prediction models

◆ **Models predicted DM-1 maximum 1-L amplitudes to be from 0.5 to 1.9 psi zero-to-peak.**

- Maximum DM-1 value measured was 0.46 psi
  - 2-L and 3-L amplitudes were also lower than other historical motor amplitudes.
- Similar oscillation measurements were found on DM-2 and DM-3 static tests as well.
  - Maximum 1-L amplitude measured on DM-2 and DM-3 were 0.51 and 0.49, respectively

◆ **Improvements made to analytical models, enhancing the prediction accuracy**

- Test data and improved analytical models made evident that fewer, or no, mitigation mechanisms would be needed

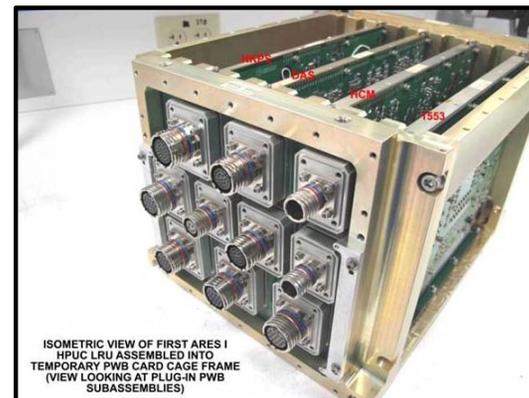


**DM-1 1-L Maximum Pressure Oscillation Amplitude Comparison**

- ◆ **Booster avionics boxes control the stage, take measurements, and communicate with the vehicle.**
  - Ignition Separation Controller (ISC)
  - Hydraulic Power Unit Controller (HPUC)
  - Booster Control Power Distribution Unit (BCPDU).
- ◆ **Initial test phase manufactured the first generation (Rev 0) components and Engineering Development Units (EDUs).**
  - Conducted hard environment testing (thermal) on each EDU component to evaluate the performance during flight-like conditions.
- ◆ **The next phase of tests, single-string, integrated Rev 0 EDUs into a single-string configuration to simulate flight-like commands through the BCPDU to the ISC and HPUC.**
- ◆ **Multi-string testing integrated Rev 1 EDUs into a full-scale forward structure model in a flight-like configuration.**
  - Tested the spacing and cable routing between the boxes in a flight-like model.
  - EDUs were then subjected to environmental qualification level testing (vibration, shock, EMI, salt/fog, etc.).
  - Avionics boxes qualified to the environmental bounds through all phases of flight.
- ◆ **Controlled Demonstration Test at MSFC**
  - Managed the thrust vector control actuators and tested the avionics boxes' control commands during simulated flight



ISC integrated into Controlled Demonstration Test at MSFC



- ◆ **In 2008, NASA established a team to evaluate the design-to-cost (DTC) estimate and develop ways to significantly reduce production cost for the Ares I First Stage booster.**
  - Identified NASA's culture of insight and oversight as a significant cost driver.
    - NASA/ATK typically maintain high levels of interface without restricting interaction points
  - NASA reduced the number of official avenues for contractor direction, also reducing ATK workforce burden
- ◆ **Beginning in 2011, NASA and ATK began utilizing a value stream mapping (VSM) process to identify ways for streamlining/optimizing the manufacture and assembly of SLS boosters.**
  - Approximately 750 total changes
    - Includes 423 process improvements approved to eliminate source of waste
    - More than 400 moves eliminated
    - All Class I/IR and/or Type I \*PC\* changes require NASA ERB/ECB approval
      - Booster ERB/ECB has approved 114 process improvements to date
    - 46% cycle time improvement and reduce projected costs by millions of dollars, with no significant increased risk to the hardware, mission, and program
    - All major motor production areas have completed their respective VSMs
    - BSM and Test Area VSMs are scheduled for May/July 2012, respectively

- ◆ **SLS booster provides primary liftoff propulsion to the SLS vehicle**
  - NASA is leveraging existing contracts and assets for Block 1 booster design
  - DDT&E for the advanced booster will be competitively bid and used on the Block 1A/2 SLS vehicles
- ◆ **Block 1 booster design is derived from and incorporates improvements over SSP RSRM**
  - ~25% greater total impulse
  - Asbestos-free insulator with ~20% reduced weight
  - Increased sag in motor static tests resulted in erosion wash not previously seen
    - Being addressed with nozzle changes and additional support during test
  - Significant development in new avionics suite
  - Considerable progress in reducing costs
- ◆ **SLS Booster has successfully completed component-level and significant major subsystem tests**
  - Three full-scale development motor tests
  - New booster avionics box testing
- ◆ **Over the coming years, several major milestones are planned for the SLS Booster Team**
  - Booster Readiness Review: June/July 2012
  - Booster Preliminary Design Review: spring 2013
  - Avionics Flight Control Test #2: September 2012
  - QM-1 static test: spring 2013
  - QM-2 static test: fall 2014

- ◆ **SLS booster provides primary liftoff propulsion to the SLS vehicle**
  - NASA is leveraging existing contracts and assets for Block 1 booster design
  - DDT&E for the advanced booster will be competitively bid and used on the Block 1A/2 SLS vehicles
- ◆ **Block 1 booster design incorporates improvements over SSP RSRM**
  - Asbestos-free insulator
  - New avionics
  - Improved motor performance
- ◆ **SLS Booster has successfully completed hundreds of component tests as well as several significant major subsystem tests:**
  - Full-scale development motor tests
    - Three full-scale tests helped characterize and predict:
      - Motor's performance of unique thrust-time profile
      - Nozzle performance
      - New PBI-NBR Insulation
      - Internal motor pressure oscillations.
  - New booster avionics box testing
    - Component-level
    - Single-string configuration
    - Multi-string configuration
- ◆ **Over the coming years, several major milestones are planned for the SLS Booster Team**
  - Booster Readiness Review: June/July 2012
  - Booster Preliminary Design Review: spring 2013
  - Avionics Flight Control Test #2: September 2012
  - QM-1 static test: spring 2013
  - QM-2 static test: fall 2014

# Questions

